Energy Economics 74 (2018) 802–812

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Cap prices or cap revenues? The dilemma of electric utility networks

Alrick Campbell

Crawford School of Public Policy, The Australian National University, 132 Lennox Crossing, Acton, ACT 2601, Australia
Department of Economics, The University of the West Indies, Mona Campus, Kingston 7, Jamaica

ARTICLE INFO

Article history:
Received 3 February 2017
Received in revised form 18 July 2018
Accepted 27 July 2018
Available online 2 August 2018

JEL classification:
D42
I30
L51
L94

Keywords:
Electricity
Price cap
Ramsey
Revenue cap
Welfare

ABSTRACT

In this paper I analyse the behaviour of a monopoly electricity provider that serves three distinct markets under a price cap or revenue cap plan. I make comparisons in terms of their effects on price setting, energy conservation, and social welfare.
In addition to contravening the Ramsey pricing rule, I find that under conditions of information asymmetry, when demand becomes more elastic or marginal cost increases, revenue cap price increases are larger relative to price cap regulation. In this specific setting, revenue cap price increases can encourage energy conservation but is less likely to do so when marginal cost is large in a market that is more elastic relative to others. In contrast to a price cap plan, these overall results show that revenue cap schemes are welfare-reducing.
For public policy decision-making purposes, price cap regulation is more desirable especially in developing economies that often experience substantial inflationary pressures from global oil market developments but is less suitable than revenue cap regulation when electricity supply constraints and climate change are major policy concerns.

1. Introduction

Public network industries such as electricity markets were traditionally governed by rate-of-return (ROR) regulation. However, this regulatory approach was often criticised for its lack of incentives in minimising costs and tendency to encourage too much investment in capital (Averch and Johnson, 1962; Laffont and Tirole, 1993; Sappington, 1994). As electricity sectors underwent major market reforms, ROR was eventually replaced with incentive regulation schemes to constrain the market power of privatised utilities and encourage efficiency.

In light of the many incentive schemes that exist, advocates like the Australian Energy Regulator (2013) and the Jamaica Public Service (2014) claim that replacing price caps with revenue cap regulation will provide greater incentives for cost recovery and investment in energy efficiency and promote energy conservation in electricity markets. The ineffectiveness of price cap regulation in encouraging energy conservation from a demand-side perspective is widely discussed in the literature (see, for example, Wirl, 1995; Sappington and Weisman, 2010). However, proponents of price cap regulation argue that in contrast to price cap regimes, revenue cap regulation incentivises price increases that depart from the Ramsey pricing rule, creates output restrictions, and may lead to major reductions in social welfare (Comnes et al., 1995; Crew and Kleindorfer, 1996b; Decker, 2009). Others such as Dutra et al. (2015) find that price cap regulation induces incentives for supply-side energy efficiency by reducing network losses while both schemes can be implemented to achieve the same level of welfare.

The arguments in support of a particular incentive pricing plan have evolved from a theoretical framework without knowledge of behavioural differences in practice. Therefore, I aim to reconcile these arguments by using actual industry parameters to quantitatively assess differences in revenue and price cap schemes in terms of prices, energy conservation, and welfare. This represents the first known attempt at performing a comparative analysis of both schemes using parameters calibrated with industry data. I take a demand-side management focus and use a firm operating under a vertically separated electricity market structure with a monopoly in the downstream (distribution and retail) segment. To capture the regulator's problem of information asymmetries recognised by Laffont and Tirole (1993), I also address cost and demand uncertainties.

E-mail addresses: alrick.campbell@anu.edu.au, alrick.campbell02@uwimona.edu.jm.

https://doi.org/10.1016/j.eneco.2018.07.029

Understanding differences between either scheme has important policy implications. For example, developing countries that generate a substantial portion of their electricity from imported fuels are more prone to price instability, and may show a preference for price cap regulation to ease inflationary pressures on the local economy. This is of particular significance when there is substantial pass-through to domestic inflation. However, if the argument for energy conservation holds for a revenue cap, heightened security of supply and climate change concerns may necessitate the use of revenue cap regulation which favours price increases. This is important since a climate-induced increase in electricity demand can give rise to higher emissions during peak demand hours (Chen et al., 2015). These emissions could be reduced through demand flexibility arising from higher renewable energy penetration, but Kroeze et al. (2004) argue that end-use efficiency also has the potential to create substantial reductions in greenhouse gas emissions in developing countries. In this particular case, caution should be exercised since increased prices could result in the substitution of oil and gas-fired generating units for cheaper and more carbon-intensive technologies such as coal (Xie et al., 2014). In general, choice of a specific scheme will involve trade-offs and is dependent on the goals of government and regulators.

To test the theoretical arguments about price setting, energy conservation, and social welfare for both schemes, I use a constrained optimisation problem similar to Brennan (1989) and De Villemeur et al. (2003), and apply it to the electricity network in Jamaica. I find that under certain conditions, relative to price cap regulation, revenue cap regulation creates conditions for higher and inefficient price setting, encourages energy conservation, and is welfare-reducing. The remainder of the paper is organised as follows: Section 2 provides a brief overview of market reforms and various incentive regulation schemes. Section 3 presents the main electricity pricing models used. In Sections 4 and 5, I calibrate each pricing model with parameter values that approximate the key characteristics of the regulated entity, discuss the data used, perform analyses, and report their results. Section 6 highlights the main conclusions and policy implications of the study.

2. Market reforms and incentive regulation

Policymakers in both developed and developing countries have long believed that it is most efficient for electricity to be supplied by a single firm. It is this thinking that gave rise to the creation of a natural monopoly characterised by common ownership and sole responsibility for electricity generation, transmission and distribution services. Joskow (1997) postulates that utilities have maintained this vertically integrated structure because of significant operating and investment complementarities that allowed them to benefit from economies of scale and scope. However, this traditional belief is increasingly being challenged. Indeed, many developed and developing countries have implemented major structural and regulatory reforms to promote competition within the electricity sector.

Large-scale reform measures in electricity sectors across developed countries dates back to as early as the 1980s. These reform measures were largely aimed at introducing private sector participation and the promotion of competition through economic deregulation. In contrast, the introduction of substantial reforms in the electricity sectors of developing countries has been a more recent phenomenon. It was not until the early 1990s and 2000s that such reforms were initiated. Bacon and Besant-Jones (2001) theorize that comparatively, introducing electricity reform measures in developing countries is more challenging than in developed countries and every effort should be made to ensure that such measures are both desirable and politically feasible before implementation.

Based on the European Bank for Reconstruction and Development (EBRD) definition of sector transition which has five levels, ranging from extensive government control (Level 1) to large-scale private involvement (Level 4+), electricity reform measures undertaken in many developing countries can be categorised according to Level 4. This involves the separation of the industry into generation, transmission, and distribution; setting up of an independent regulator with rules for cost-effective tariff-setting formulated and implemented; and some degree of liberalisation (The European Bank for Reconstruction and Development, n.d.). This could also include separation of the distribution and retail segments as is the case in many developed countries such as Nordic states.

2.1. Incentive regulation plans

Traditionally, rate of return regulation has been the primary means of regulating utilities, where the utility is allowed to recover its costs and a guaranteed rate of return. This pricing methodology has been criticised on a number of grounds, most notably of which is the incentive it gives to firms to over-invest in capital as was first pointed out by Averch and Johnson (1962). This has led to the development of various incentive regulation schemes. Common forms of these schemes that exist in practice include price cap regulation, revenue cap regulation, sliding-scale regulation, yardstick competition, and menu of contracts regulation. Relative to ROR where consumers bear all the risks, since operating and investment costs are reflected in price increases, differences among incentive schemes are largely explained by risk allocation and incentives.

In the United Kingdom and many Latin American countries, price cap regulation is the preferred form of regulation used to incentivise cost reductions and constrain the market power of privatised utilities. Under a price cap, constraints are placed on the path of prices for services provided by a regulated firm during a fixed period of time. With prices constrained, firms increase profits by reducing cost or increasing sales. Therefore, unexpected cost changes and volumetric risk are borne mostly by the firm. This reduces the moral hazard problem present in managerial effort, but if regulators have limited knowledge of the firm's ability to reduce costs this can potentially allow the firm to extract significant rent from consumers or it can lead to the firm's detriment (Joskow, 2007). Another drawback of price caps is the potential to deter investment and reduce service quality (Sappington, 2002) as effort is expended at minimising cost, though Banerjee (2003) does not find any evidence that price cap causes deterioration in service quality. Despite its shortcomings, Armstrong and Vickers (2012) show that social welfare can increase when regulated firms operate under a price cap by limiting cross-subsidizing pricing behaviour.

In order to overcome volumetric risk, European countries such as Norway and Sweden show a preference for revenue cap regulation (Jarvis, 2011). In its simplest form, constraints are placed on the regulated firm's revenues rather than prices. Hirst et al. (1994) advocated for the use of revenue caps based on the idea that they provide greater incentives for demand-side management compared to price cap regulation. Though both schemes encourage cost reduction, a price cap encourages higher sales while a revenue cap promotes energy savings through flexible price adjustments. Under a binding revenue cap, the firm can increase profit by reducing costs through reductions in output or increasing price. Revenue caps are more suitable in situations where the positive covariance between costs and sales is low. If tariffs are reflective of the utility's costs and demand is inelastic, a price rise will reduce the quantity of electricity demanded and total costs, while increasing revenue. With the revenues of the utility capped, the reduction in costs will translate directly into profits. This incentivises price increases for the least inelastic market segments served by utilities. This idea was advanced by Jamison (2007) and was similarly supported by Lantz (2008) who

emphasized that use of revenue caps is a 'bad idea' when detailed information about the firm's cost function is not available. A revenue cap may also lead to substantial reductions in social welfare since the regulated firm is likely to deviate from Ramsey pricing by charging higher prices to consumers as demand becomes more elastic (Comnes et al., 1995; Crew and Kleindorfer, 1996b). Crew and Kleindorfer (1996b) also claim that revenue caps provide incentives for price increases that could exceed the unregulated monopoly level resulting in substantial reductions in social welfare.

Price caps are bad at extracting information about the firm's ability to reduce costs and can lead to supernormal profits, but provide good incentives for managers to minimise production costs – a limitation of ROR schemes. As a result, sliding-scale regulation serves as a compromise between price cap and ROR schemes (Lyon, 1996). Many incentive regulation schemes are hybrid in nature, but the general rule is that sliding-scale regulation allows for provisions that redistribute extra rents to customers if the company earns profits in excess of the allowed rate of return. They can also be symmetric – allowing for price increases when the firm is exposed to losses beyond a certain limit (Parker and Kirkpatrick, 2005). In either case, downside and upside risks are shared by consumers and the firm. However, information requirements can be substantial relative to other schemes (Parker and Kirkpatrick, 2005) and the utility may not be motivated to pursue efficiency as strongly when excess profits are shared (Crew and Kleindorfer, 1996a).

In terms of yardstick competition, this entails comparing firms engaged in the same line of business with each other. To infer the efficient cost level, the regulator uses the costs of comparable firms as a benchmark (Shleifer, 1985). As the firm's price and own cost drivers are delinked, this regulatory mechanism provides the regulated firm with robust incentives to employ optimal effort in reducing costs below the industry average since it is the sole beneficiary of these cost reductions. Some limitations of this model include possible collusive behaviour among firms (Potters et al., 2004) and the difficulty in inferring the efficient cost level when regulated entities operate in an heterogeneous environment (Jarvis, 2011). For instance, it would be misleading or impractical to compare firms that differ in terms of geographical location and customer base. However, the problem related to differences in environmental operating conditions can be minimised by using techniques such as random parameters stochastic frontier analysis (SFA) and stochastic non-parametric envelopment of data (StoNED) which combines features of SFA and data envelopment analysis (DEA).[1] This regulatory approach is typically used alongside other schemes and is generally applicable in developed countries that often have unbundled market structures. Norway's incentive regulation scheme also has elements of yardstick regulation (see Appendix A).

Laffont and Tirole (1993) argue that optimal incentive schemes should be designed to address the principal-agent problem associated with asymmetric information. The principal (regulator) has far less information about the utility's (agent) operations. For instance, regulated firms are better informed about the cost of providing electricity and consumer demand behaviour. Given the positive and negative attributes of the various schemes discussed previously, the regulator can do even better by presenting firms with a choice of regulatory contracts (Laffont and Tirole, 1986, 1993). This is called 'menu of contracts' regulation and induces the optimal behaviour of firms. Such contracts are often complex and require substantial information, but Rogerson (2003) showed that in a real-world context, a menu consisting of two simple regulatory contracts (fixed price or cost of service) is easy to understand and is often enough to capture the majority of surplus that a more complex contract would deliver. Further empirical evidence by Kopsakangas-Savolainen and Svento (2010) show that menu of contracts regulation provide sufficient incentives to solve moral hazard and adverse selection problems.

The preceding discussion provides a comparison of the many incentive regulation schemes that exist in practice, but in this study I only analyse differences between price and revenue cap regulation to reconcile arguments put forward by proponents and opponents of both schemes. However, since Jamaica's electricity sector is used in the application, I discuss key tenets of the industry in more detail in the next section.

2.2. Price regulation in Jamaica

The initial motivation behind structural reform measures implemented in Jamaica largely resulted from the need to improve financial performance and operational efficiency of government-owned enterprises. This was primarily seen as an opportunity to relieve taxpayer burden and to improve the operational efficiency of the utility rather than a genuine means to introduce competition. The process of reform measures undertaken can be broadly divided into three categories: (1) private sector participation; (2) structural reforms to address the vertical separation of electricity supply functions such as generation, transmission and distribution; and (3) regulatory reforms that codify behaviour and provide incentives for utilities to operate efficiently.

In 2001, the Government of Jamaica sold 80% of its stake in the Jamaica Public Service – the sole electricity supplier in Jamaica. Majority share ownership is held jointly between Marubeni Caribbean and Korea East-West Power Company Limited (Jamaica Public Service, 2013b). The government of Jamaica retained 19% while the final 1% was owned by minority shareholders. Under the Office of Utilities Regulation (OUR) Act of 1995, regulation and oversight of the sector remains the responsibility of the OUR which was established in 1997 by an Act of Parliament. Its responsibilities include the issuance and review of licences, review of five-year tariff applications and requests for annual increases, and the investigation of breaches by the electricity provider. In addition to this, the OUR issues and reviews Requests for Proposals (RFPs) for capacity addition to the electricity grid (Office of Utilities Regulation, 2004).

Jamaica's electricity generation sector was fully liberalised in 2004 but most of the approximately 820 MW of electricity needed to meet demand in the country is still generated by the JPS. The majority of JPS' electricity is generated from imported fossil fuel, but it also owns eight hydro-electric plants with capacity of approximately 25 MW. Of the total required capacity of the country, 215 MW of capacity is available to the distributor under long-term (20 years) power purchase agreements (PPAs) with the four independent power producers (IPPs).

Even though competition has been introduced into the generation segment and regulatory entry barriers have been eliminated, the JPS retained its vertical structure and continues to perform the functions of generation, transmission, and distribution. On the generation side, a number of private entities operate alongside the state-owned generator to supply electricity to the national grid owned and operated by the monopoly distributor (Jamaica Public Service, 2013b).

During the 2001 period in which the electricity company was privatised, the OUR introduced price cap regulation to incentivise improvements in operational efficiency. The specific form of the cap used is

$$p_t = p_{t-1}(1 + dI + X + Q + Z) \quad (1)$$

where p_{t-1} is the non-fuel tariff at the beginning of the price cap period, dI accounts for inflation and exchange rate devaluation, X

[1] For a detailed exposition of these techniques, see Kuosmanen et al. (2013).

is an efficiency target, Q is the allowed price adjustment to reflect changes in the quality of service provided to the customers, and Z is the allowed rate of price adjustment for special reasons not captured by the other elements of the formula (Office of Utilities Regulation, 2004). Under this regime, the non-fuel tariff accounts for all costs except fuel which is passed on fully to customers (irrespective of the price of fuel) and is subject to heat rate and electricity distribution loss adjustments. It was originally implemented for three years with X and Q set to zero. The idea was to allow the utility some time to improve efficiency and give the regulator time to develop appropriate measures of X and Q before the regime was fully implemented in June 2004 and the price cap period extended to five years.

In 2014 the JPS requested that the Office of Utilities Regulation change the existing price cap plan to a revenue cap (Jamaica Public Service, 2014). Without any empirical justification, the electricity provider argued that a revenue cap will ensure that sufficient revenues are earned to cover all prudent costs in addition to the return on investment. Additionally, it advocated for a revenue cap on the basis that it encourages energy conservation and efficiency. After nine months of deliberations, the regulator rejected the proposal in January 2015 using theoretical arguments similar to that of Comnes et al. (1995) and Crew and Kleindorfer (1996b) even though it was recently approved in January 2016. In light of this situation, the regulated electric utility in Jamaica serves as a natural case study to empirically test for differences in price setting, energy conservation, and welfare since it had an established price cap regulatory regime that has been in operation since 2001 and now operates under a revenue cap scheme.[2]

3. Optimisation models

To examine how price cap regulation compares with revenue cap regulation, I first present a basic model of a regulated firm that operates under a vertically separated market structure. This is then followed by the specific set-up of the Ramsey (1927) pricing, price cap, and revenue cap constrained optimisation problems.

The basic model consists of a regulated firm that has a natural monopoly in downstream electricity operations where it is responsible for retail and distribution services. The regulated firm may or may not operate in the upstream segment (electricity generation), but this is immaterial as the focus is on how the regulatory policy option influences firm behaviour in downstream operations.

The regulated natural monopoly supplies a homogeneous good – electricity – to $i = 1 \ldots n$ distinct markets: residential, commercial, and industrial. If c_i is marginal cost for market i, q_i is the electricity sold in each market, p_i is the retail price of electricity in market i, and F is common fixed cost; the firm seeks to maximise the profit function at time t such that

$$\pi_t = \sum_{i=1}^{n} [p_{i,t} - c_{i,t}]\, q_{i,t}\,(p_{i,t}) - F_t \tag{2}$$

To simplify the model, I assume that demand in each market segment is independent of each other so that the cross-price elasticities are zero. Residential consumers, for instance, do not use more electricity in response to an increase in the price of commercial or industrial electricity tariffs.

I also assume a constant-elasticity demand function for each market segment of the form

$$q_{i,t}\,(p_{i,t}) = k_i {p_{i,t}}^{-\epsilon_i}, \quad 0 \le \epsilon_i < 1 \tag{3}$$

where $\epsilon_i = -\frac{\partial q_{i,t}}{\partial p_{i,t}} \cdot \frac{p_{i,t}}{q_{i,t}}$ is the elasticity of demand for electricity with respect to electricity tariffs. This functional form assumes that there will be some demand for electricity irrespective of the price if $k_i > 0$. This demand function is discussed in more detail in Section 4.1.

Using the inverse demand function $p_{i,t}\,(q_{i,t})$, total value V to consumers of consumption quantity $q_{i,t}$ is the area under the demand curve given as

$$V(q_{1,t}, \ldots, q_{n,t}) = \sum_{i=1}^{n} \int_0^{q_{i,t}} p_{i,t}\,(q_{i,t})\, dq_{i,t}. \tag{4}$$

We can then determine consumer surplus CS by evaluating Eq. (4) over the range $(0, q_{i,t})$ and substituting Eq. (3) into its solution such that

$$CS(p_{1,t}, \ldots, p_{n,t}) = V(q_{1,t}\,(p_{1,t}), \ldots, q_{n,t}\,(p_{n,t})) - \sum_{i=1}^{n} p_{i,t} q_{i,t}(p_{i,t}) \tag{5}$$

On the other hand, the value of producer surplus PS is calculated as

$$PS(p_{1,t}, \ldots, p_{n,t}) = \sum_{i=1}^{n} [p_{i,t} - c_{i,t}]\, q_{i,t}\,(p_{i,t}) \tag{6}$$

3.1. Ramsey pricing

The first-best solution for pricing electricity is marginal cost pricing because it maximises social welfare. However, marginal cost pricing will result in the regulated firm making a loss, thus requiring the regulator to opt for the second-best Ramsey (1927) pricing rule which maximises social welfare subject to the constraint that the firm break even. Under this pricing rule, the firm will increase prices, above marginal cost, for goods with inelastic demand. In contrast, goods with higher elasticities of demand will have lower prices. Ramsey pricing therefore serves as natural benchmark for analysing the differences between price and revenue cap schemes and is discussed first.

Formally, a regulator that is well-informed about the firm's cost and demand structure will aim to maximise social welfare defined as the sum of consumer surplus CS and producer surplus PS, subject to the break-even constraint. Thus, Ramsey prices maximise the following Lagrangian:

$$\max_{p_{i,t},\lambda} \mathcal{L} = CS + PS - \lambda \left(\sum_{i=1}^{n} [p_{i,t} - c_{i,t}]\, q_{i,t}\,(p_{i,t}) - F_t \right) \tag{7}$$

The first order condition with respect to price is

$$\frac{\partial \mathcal{L}}{\partial p_{i,t}} = p_{i,t} \frac{\partial q_{i,t}}{\partial p_{i,t}} - c_{i,t} \frac{\partial q_{i,t}}{\partial p_{i,t}} - \lambda \left[q_{i,t} + p_{i,t} \frac{\partial q_{i,t}}{\partial p_{i,t}} - c_{i,t} \frac{\partial q_{i,t}}{\partial p_{i,t}} \right] = 0 \tag{8}$$

Solving Eq. (8) results in

$$\mu_i = -\left(\frac{\lambda}{1-\lambda} \right) \frac{1}{\epsilon_i} \qquad\qquad i = 1, \ldots, n \tag{9}$$

where $\mu_i = \frac{p_{i,t} - c_{i,t}}{p_{i,t}}$ and λ is the shadow price indicating how much social welfare will increase when profits are reduced by one dollar.

With Ramsey prices, the mark-up of price over cost is inversely proportional to the price elasticity of demand in each market. This implies that prices and mark-ups are higher in market segments with lower price elasticity of demand (Baumol and Bradford, 1970). Under

[2] Examples of other countries that use price and revenue cap regulation schemes are provided in Appendix A.

the assumption that price is greater than marginal cost, we have that $\lambda < 0$. However, if $\lambda = 0$, the break-even constraint is not binding and Eq. (9) reduces to first-best pricing where price equals marginal cost, that is $p_{i,t} = c_{i,t}$.

3.2. Price cap

In light of information asymmetries that usually exist between the regulator and the regulated entity; Laffont et al. (1996) and De Villemeur et al. (2003) argue that the regulator can decentralize Ramsey prices using a global price cap formula that allows the utility to choose its prices when there is uncertainty about the firm's demand and cost structure. To move directly to Ramsey prices, quantity weights under the price cap must be proportional to actual quantities generated from the Ramsey pricing equation in Section 3.1.

To illustrate the mechanics of this process, I follow Neu (1993) and assume that the regulated firm maximises profit subject to a global price-cap constraint where the weighted average of price changes of the n regulated market segments between $t-1$ and t must not exceed zero shown by

$$\sum_{i=1}^{n} (p_{i,t} - p_{i,t-1})\, w_i \leq 0 \tag{10}$$

where w_i is the weight of service i in the consumption basket. Note that the Jamaican case in Eq. (1) is similar to Eq. (10) except that dI, X, Q, and Z set to zero to allow for ease of comparison with the revenue cap.

Combining Eqs. (2) and (10) gives the firm's objective function as

$$\mathcal{L} = \sum_{i=1}^{n} [p_{i,t} - c_{i,t}]\, q_{i,t}(p_{i,t}) - F_t - \lambda\left(\sum_{i=1}^{n} (p_{i,t} - p_{i,t-1})\, w_i\right) \tag{11}$$

where λ is the Lagrange multiplier so that differentiating with respect to $p_{i,t}$ gives the first order conditions

$$\frac{\partial \mathcal{L}}{\partial p_{i,t}} = q_{i,t} + p_{i,t}\frac{\partial q_{i,t}}{\partial p_{i,t}} - c_{i,t}\frac{\partial q_{i,t}}{\partial p_{i,t}} - \lambda w_i = 0 \tag{12}$$

By setting $w_i = q_{i,t}$, it is easy to see why the global price cap satisfies the inverse elasticity rule where

$$\mu_i = (1-\lambda)\frac{1}{\epsilon_i} \qquad i = 1, \ldots, n. \tag{13}$$

In general, Eq. (13) is different from Eq. (9) because the firm is allowed to earn a profit under a price cap, but if the exogenous weights are proportional to each market's electricity consumption level realised under Ramsey pricing such that $w_i = q^*_{i,t}$, one readily verifies that the Lagrange multiplier of the price cap constraint and Ramsey equation are related as follows:

$$\lambda = \frac{1}{(1-\lambda^*)} \qquad i = 1, \ldots, n. \tag{14}$$

where λ^* is the Lagrange multiplier given by the solution to Eq. (7) and $q^*_{i,t}$ is Ramsey quantity weight. Thus, the prices induced by the global price cap are optimal and are the same as those given by the Ramsey solution to Eq. (7).

With $0 < \lambda < 1$, the global price cap moves towards Ramsey prices as λ increases and the constraint becomes more binding. Thus, the prices and quantities derived maximise welfare subject to prices not exceeding the cap. This encourages cost-minimising behaviour since inefficient production practices will only reduce profits without generating any additional welfare (Brennan, 1989).

3.3. Revenue cap

If the firm maximises profit in accordance with Eq. (2), the Lagrangian for a regulated firm that is subject to a revenue cap is

$$\mathcal{L} = \sum_{i=1}^{n} [p_{i,t} - c_{i,t}]\, q_{i,t}(p_{i,t}) - F_t - \lambda\left(\sum_{i=1}^{n} p_{i,t} q_{i,t}(p_{i,t}) - \sum_{i=1}^{n} p_{i,t-1} q_{i,t-1}(p_{i,t-1})\right) \tag{15}$$

Differentiating with respect to $p_{i,t}$ gives the first order conditions

$$\frac{\partial \mathcal{L}}{\partial p_{i,t}} = q_{i,t} + p_{i,t}\frac{\partial q_{i,t}}{\partial p_{i,t}} - c_{i,t}\frac{\partial q_{i,t}}{\partial p_{i,t}} - \lambda\left(q_{i,t} + p_{i,t}\frac{\partial q_{i,t}}{\partial p_{i,t}}\right) = 0 \tag{16}$$

which can be rewritten as

$$\mu_i = (1-\lambda)\frac{1}{\epsilon_i} + \lambda \qquad i = 1, \ldots, n \tag{17}$$

where $\mu_i = \frac{p_{i,t} - c_{i,t}}{p_{i,t}}$.

As long as $\epsilon_i < 1$, which is usually the case for the utility industry, λ will be greater than 1 and the revenue cap delivers prices that satisfy an interior solution, but deviate from the Ramsey pricing rule. This can be easily seen by rearranging Eq. (16) so that

$$p_{i,t} = \frac{c_{i,t}\epsilon_i}{(1-\lambda)(\epsilon_i - 1)} \qquad i = 1, \ldots, n \tag{18}$$

This means that prices are higher in markets with more elastic demand and lower in inelastic markets as the revenue cap becomes more binding.

4. Calibration of model parameters

To solve the constrained optimisation models, demand and cost parameters are needed. In this section, I discuss how these demand and cost parameters are estimated and provide a brief description of the initial data used.

4.1. Estimating the demand function

For each of the three market segments served by the regulated utility, I assume a constant-elasticity demand function of the form similar to Eq. (3), $q_{i,t}(p_{i,t}) = k_i {p_{i,t}}^{-\epsilon_i}$. This functional form follows the specification outlined in Campbell (2018) where q is also a function of income (y) and the urban share of the population (u). Since p is the variable of interest, fixed values of y and u are assumed and incorporated into a constant k_i such that $k_i = \alpha_i y_{i,t}^{\beta_i} e^{\gamma_i u_{i,t}}$.[3] An estimate of k_i is obtained after calibrating the demand function with the known parameters $q_{i,t}$, $p_{i,t}$, and ϵ_i. For simplification, zero transmission and distribution losses are assumed so that output $q_{i,t}$ of electricity generated is also extracted by consumers.

4.2. Cost parameters

Up-to-date marginal cost data are not publicly available, but the Jamaica Public Service (2014) publishes data on total variable cost exclusive of the fuel component. Since the original data does not

[3] The constant term is α_i while β_i and γ_i are the respective coefficients of income and the urban share variable for each market.

give any information about the variable cost attributable to each customer class, the marginal cost for electricity in market i at time t is approximated as

$$c_{i,t} = \frac{\sum_{i=1}^{n} VNF_{i,t} \times \varphi_{i,t}}{qs_{i,t}} + \frac{FC_t}{Q_t} \tag{19}$$

where $VNF_{i,t}$ is the variable non-fuel cost, FC_t is the total fuel cost, Q_t is the aggregate electricity sold, $qs_{i,t}$ is the amount of electricity sold to customer block i, and $\varphi_{i,t}$ is the allocation factor for each block.

Following a similar approach by Jamaica Public Service (2014), a uniform fuel charge FC_t/Q_t is ascribed to each customer block. To calculate the allocation factor for each block, I assume that the variable non-fuel cost can be allocated based on the share of total energy and demand charge for each block. Marginal costs were computed across the twelve blocks of consumers and simple averages taken for the three main customer segments.

4.3. Data

I use 2013 data for the JPS which currently serves twelve blocks of customers. These blocks have been reclassified into three main customer segments: residential (Rate 10), commercial (Rate 20/40), and industrial (Rate 50). Each rate class has different customer blocks. For example, Rate 10 may include customers that consume below 100 kWh per month and those that consume above that limit. Except for the demand elasticities obtained from Campbell (2018), the main source of the data used is Jamaica Public Service (2013a).

Table 1 shows the initial data on electricity prices (tariffs), quantities, price elasticities of demand, and marginal costs for the regulated firm attributable to each customer segment, as well as total fixed costs. The average unit price of electricity is denominated in US$ and calculated as total revenue attributable to each customer class divided by their respective sales volume. In 2013, residential customers consumed approximately 996 GWh of electricity at an average price of US$0.3891 per kWh. Commercial customers were billed for 1366 GWh at US$0.3640 per kWh while the smallest customer class, industrial customers, was billed 605 GWh at US$0.3030 per kWh.

The absolute value of the price elasticity of demand for each customer segment is 0.82, 0.15, and 0.25, respectively. Campbell (2018) derived these long-run price elasticity of demand estimates over the period 1970 to 2014 using the bounds testing approach to cointegration. The model he estimated was tested for parameter constancy and passed a range of diagnostics tests covering serial correlation, normality, functional form, and heteroscedasticity.

Marginal cost, measured in US$ per kWh, is 0.2710, 0.2735, and 0.2413 for the residential, commercial, and industrial segments, respectively. The fixed cost estimate for JPS is US$413 million and is also obtained from Jamaica Public Service (2014). It represents approximately 89% of the company's total non-fuel costs. This cost mainly includes depreciation, cost of capital, and purchased power from independent power producers.

5. Analysis and discussion

Using the solution and functions provided in the previous sections, prices and quantities are calculated for the price cap and revenue cap schemes for the three markets served by the utility provider. Recall that in the case of the price cap, the weights applied to Eq. (10) are based on the quantities obtained from maximizing Eq. (7). I also calculate the social welfare changes associated with each scheme using 2013 tariffs as the benchmark case.

5.1. Prices, output, and welfare changes

The price estimates of the constrained optimisation problems are reported in Table 2 for both regulatory options. For comparison purposes, I also include the marginal cost estimates and original tariffs for 2013.

Three key findings emerge from Table 2. Firstly, prevailing tariffs for each customer segment in Jamaica contravene the inverse elasticity rule which requires the mark-up of price over marginal cost to be inversely proportional to the elasticities of demand. For example, residential consumers are most responsive to price changes, but paid the highest rate for electricity in 2013 when compared to the other customer groups. In a similar application to utility networks in Finland, Kopsakangas-Savolainen (2004) also found that prevailing electricity prices were not efficiently set. Secondly, optimal price setting – a price cap based on Ramsey weights – would require an increase in price for the commercial and industrial customers of 37% and 12%, respectively; and a drop in price for residential customers (27%). In this situation the inverse elasticity rule is satisfied since the price mark-up is lowest in the least inelastic residential market. This also implies that existing consumers in the commercial and industrial markets are being cross-subsidized by residential consumers. Finally, prices under a revenue cap contravene the inverse elasticity rule. Specifically, residential prices would be approximately 13 times larger than existing tariffs with a 43% decline and 13% increase observed in the commercial and industrial markets, respectively. For the commercial segment, price also fall below marginal cost under the revenue cap.

Table 1
Initial data used in constrained optimisation models[a].

Variables	Coefficient	Residential	Commercial	Industrial
Constant (in millions)	k_i	459	1174	449
Original tariff (US¢/kWh)	$p_{i,t}$	38.91	36.40	30.30
Original quantity (GWh)	$q_{i,t}$	996	1366	605
Demand elasticity	ϵ_i	0.82	0.15	0.25
Marginal cost (US¢/kWh)	$c_{i,t}$	25.83	26.05	24.82
Common fixed cost (US$, in millions)	F_t		413	

[a] Data for 2013 are used for tariff, quantity, marginal cost, and fixed cost.

Table 2
Tariff comparison under the optimal price cap and revenue cap schemes[a].

Markets	Demand elasticities	Marginal costs	Original tariffs	Optimal price cap tariffs	Optimal price cap (%Δ)	Revenue cap tariffs	Revenue cap (%Δ)
Residential	0.82	25.83	38.9	28.3532	−27.1126	500.2171	1185.905
Commercial	0.15	26.05	36.4	50.7287	36.83469	19.5422	−43.3364
Industrial	0.25	24.82	30.3	35.0512	12.21385	35.1699	12.51907

[a] Marginal costs, original tariffs, optimal price cap tariffs, and revenue cap tariffs are in US cents per kWh. Tariff changes are based on comparison with 2013 tariffs.

The preceding evidence aligns with the views of Crew and Kleindorfer (1996b) who support price caps and believe that demand-side management policies based on revenue caps are inefficient. Under a revenue cap, large increases in price will lead to a reduction in electricity sold to the more price sensitive residential customers. As electricity use falls, total costs fall more than the decline in revenues. This leads to an overall increase in the utility's profits. In fact, the utility may be more inclined to move towards peak-load pricing to induce residential consumers to shift their consumption to the off-peak period where marginal cost is lower. In this case, it is able to generate the majority of the revenue from commercial and industrial customers that continue to consume in the peak period. In general, the utility has an incentive to minimise its fixed charges, so it is not hard to understand why such a scheme is likely to undermine new investment in capacity. Without additional investments, this could also reduce the incentive for the utility to move to 100% electricity coverage (Ministry of Energy and Mining, 2009), thus conflicting with Jamaica's 2030 National Development Plan.

The price changes associated with the two schemes also have significant implications for energy conservation and societal welfare. Table 3 shows that total electricity consumption rises by 7% under the price cap scheme, but falls by about 26% under a revenue cap. This supports the conservationists view of a revenue cap. However, this ignores the possible price shock consumers are exposed to if actual demand is less than forecasted, and the utility loses revenue. Under a price cap, the utility would be forced to make the necessary investment to reduce losses and increase sales, but there is no guarantee under a revenue cap since new investments send signals of higher X-factor efficiency requirements in the future. Under a revenue cap, the utility would simply recover the losses in the next price review by charging higher prices. In developing countries, transmission and distribution losses are a major source of inefficiency making demand targets more difficult to achieve. For example, data by the US Energy Information Administration (2016) showed that transmission and distribution losses in 2013 was 26% for Jamaica compared to 2%, 8%, and 8% in countries like Trinidad and Tobago, Norway, and the UK, respectively.

The impact on social welfare, calculated as the sum of the changes in consumer and producer surpluses, is also depicted in Table 3. With 0.6 million customer accounts in 2013, the decline in social welfare under a revenue cap would approximate to US$1328 per customer per year while US$14 would be gained under a price cap. This result is supported by Raineri and Giaconi (2005), who find evidence of higher social welfare in the Chilean electricity distribution network when optimal Ramsey weights are used with the price cap. These general findings suggest that the revenue cap scheme is welfare-reducing and presents the price cap scheme as a better option for regulators.

5.2. Behavioural differences under asymmetric information

Laffont and Tirole (1993) argued that the presence of information asymmetries mean that regulators generally have limited knowledge about a regulated firm's operations. In this section, I explore the sensitivity of the price cap and revenue cap models to changes in the demand elasticity and marginal cost parameters. I also examine differences between a price cap based on Ramsey quantity weights and the use of past quantities when the regulator cannot predict the Ramsey quantities with certainty.

5.2.1. Impact of demand elasticity changes

The size of demand elasticities can have varied effects on relative prices, quantities, and welfare under each scheme. To demonstrate, I decrease residential demand elasticity threefold and show the impact of 100 linearly-spaced values over the range of 0.27 and 0.82, while holding all other variables constant. Fig. 1 shows that as demand becomes more elastic for residential customers, price falls slowly for that customer segment under a price cap but rises more sharply under a revenue cap. This trend is reversed for the commercial and industrial segments, but prices start to rise under a revenue cap when elasticity increases beyond a certain point.

The sub-plot in Fig. 1 for electricity sold shows strong support for the energy conservation view under a revenue cap since total electricity sales decline as residential consumers become more responsive to price changes. In contrast, sales increase under a price cap since the utility has a greater incentive to encourage electricity consumption. This shows that although a revenue cap transfers volume risk away from the utility to consumers, it comes at the expense of major price shocks and large reductions in social welfare.

In general, welfare per customer under the revenue cap is always negative and declines over the entire range of elasticity values. These overall results show a strong preference for price cap regulation with a tendency for welfare to increase.

5.2.2. Impact of cost changes

The generation and distribution of electricity requires large investments in infrastructure such as poles, transformers, distribution lines, and system upgrades to minimise losses. As a result, the marginal cost of supplying electricity to residential communities with low population density could be quite high relative to other sectors, but regulators do not have precise information. In this case, the utility could exploit the limited knowledge of the regulator. Given the comparatively larger demand elasticity of the residential market, it is useful to demonstrate the behavioural differences of the price and revenue cap schemes when it becomes more expensive to supply electricity to that particular market.

To undertake the numerical analysis, I simulate marginal cost changes by analysing the effects of a linear threefold increase from its current level of 25.83 US¢ to 77.49 US¢ for the residential customer segment only, while holding all other parameters fixed. The results are presented in Fig. 2.

As it becomes more expensive to supply electricity to residential customers, the tariff increases under both schemes, but at a slower rate under the price cap plan. For commercial and industrial tariffs, a steady decline is observed under both schemes, but the price cap plan has the faster rate of decline for commercial customers when marginal cost increases beyond a certain point.

By looking at the sheer magnitude of total electricity sold, a revenue cap seems like the better regulatory option in terms of energy conservation since the total amount of electricity sold is lower at every marginal cost point under a revenue cap. However, as the slope of the curves in Fig. 2 demonstrate, total output increases under a revenue cap and decreases under a price cap suggesting that the argument for energy conservation is less convincing at higher levels of marginal cost. If higher marginal costs are reflective of additional investments that target improvements in the energy efficiency of generating units, this is consistent with the view of Dutra et al. (2015) who finds that price caps incentivise supply-side energy efficiency by minimising network losses. However, in my particular setting, it is

Table 3
Output, consumer surplus, producer surplus, and total welfare changes under the optimal price cap and revenue cap schemes.[a]

Variables	Optimal price cap	Revenue cap
Total output sold (%Δ)	6.971	−25.6751
ΔCS (US$/customer)	−164.677	−1723.94
ΔPS (US$/customer)	178.6976	395.7574
ΔW (US$/customer)	14.02057	−1328.18

[a] The change in each variable is the difference between values at the original prices and the new prices calculated for each scheme.

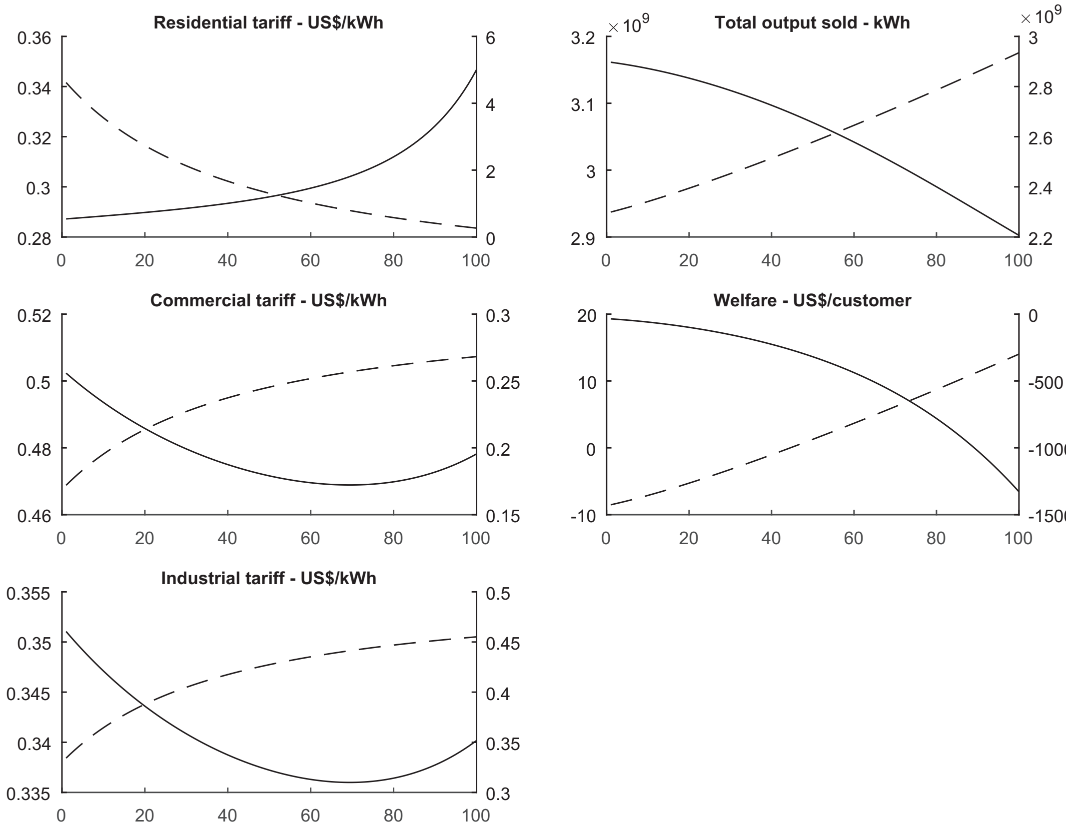

Fig. 1. Impact of residential elasticity of demand changes. Dashed line represents price cap (left axis) and solid line is revenue cap (right axis). Plots are based on residential demand elasticity changes (holding all other variables constant) with 100 points linearly spaced between and including 0.27 and 0.82.

the cost pass-through to higher end-user prices that force consumers to conserve energy.

The welfare sub-plot in Fig. 2 provides two interesting insights. First, over the range of marginal cost values, the curves for welfare per customer are convex in shape. Second, welfare is always larger under the price cap and positive in most cases, but is always negative under the revenue cap.

5.2.3. *Demand uncertainty*

Laffont et al. (1996) demonstrate that to move directly to Ramsey prices, quantity weights under the price cap must be proportional to actual quantities generated under Ramsey pricing, given conditions of information symmetry. However, if the regulator cannot accurately predict the Ramsey quantity weights, it may opt to wait, and set $w_i = q_{i,t-1}$ in Eq. (10) so that the weights are based on the consumption basket in the previous period.

The results of this exercise are detailed in Table 4 and shows that if the given elasticity estimates represent precise demand information, which the utility is likely to have, social welfare per customer would increase. Specifically, the third column of Table 4 shows that if demand is known with certainty, social welfare per customer improves to US$17.71 when compared to the US$14.02 generated under the Ramsey optimal price cap. If welfare improvement is of primary interest to regulators, this result implies that it would be more beneficial to society if the price cap regime is maintained and demand elasticities are used to discriminate among the different customer segments.

Two-part tariffs can be easily incorporated into this particular scenario by allowing the electric utility to discriminate within customer classes by using a fixed access fee and a usage charge, instead of using uniform prices. Kopsakangas-Savolainen (2004) shows that it is possible to improve welfare when a two-part tariff scheme is applied. The inclusion of the access fee allows the usage charge to be set equal to the firm's marginal cost. Therefore, the access fee for each customer class should be set to reflect the difference between price and marginal cost. This approach is justified as long as high access fees do not prevent some customers from participating in the market (Sappington and Sibley, 1992). However, the inelastic nature of electricity demand is such that all customers are likely to participate.

6. Conclusion and policy implications

In this paper I have used actual data for a monopoly distributor of electricity in Jamaica to explore performance under price cap and revenue cap regulation and make comparisons in terms of their effects on price setting, energy conservation, and social welfare. In the majority of situations analysed, the results reveal a preference for price cap regulation.

I found that in contrast to a price cap plan, a revenue cap scheme generates prices that depart from the Ramsey pricing rule with striking differences in magnitudes observed. A revenue cap supports the views of energy conservationists, but is less convincing when residential demand becomes more elastic since total electricity consumption increases at a faster rate compared to the price cap. The conservation argument also loses support at higher levels of marginal cost because of the tendency for total output to increase at a slower rate under a revenue cap and decrease at a faster rate under a price cap. This means that a price cap could potentially encourage energy conservation at relatively higher marginal cost because of additional utility investments that are reflected in end-user prices. Furthermore, I also find that in contrast to the price cap,

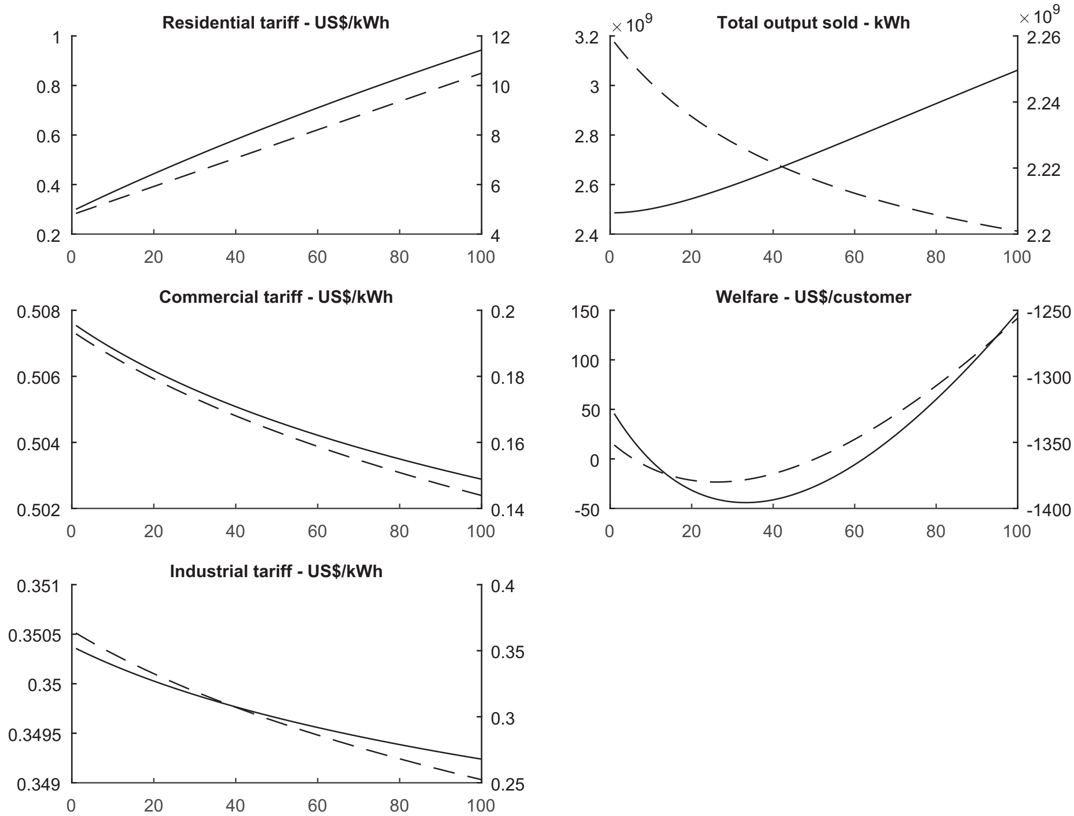

Fig. 2. Impact of residential marginal cost changes. Dashed line represents price cap (left axis) and solid line is revenue cap (right axis). Plots are based on residential marginal cost changes (holding all other variables constant) with 100 points linearly spaced between and including 25.83 and 77.49 US cents.

the inefficient price setting encouraged under a revenue cap scheme reduces social welfare or generates relatively larger welfare losses. Therefore, when information asymmetries are present, a revenue cap scheme is likely to result in more devastating effects on social welfare. Since demand uncertainty generally poses a problem for regulators, further gains in welfare are achievable under a price cap if quantity weights from the previous year are used in the regulatory process.

From a policy perspective there are certain situations that arguably favour the use of a particular scheme, especially in developing countries. For instance, if there are climate change concerns, the higher price elasticity of residential electricity demand implies that there is the potential to use the price instrument under a revenue cap to reduce electricity consumption, though this may be less effective when marginal cost is high. Furthermore, if the electricity network is supply-constrained then a revenue cap is more conducive to using prices to balance supply with demand and avoiding power outages. As developing countries generally suffer from higher rates of inflation than developed countries, an electricity provider that incurs fuel costs that are sensitive to oil prices determined in world markets will pass these costs on to customers. The price cap is not immune to this problem, but as both schemes reflect changes in input costs, nominal prices will rise faster under a revenue cap scheme. Therefore, a revenue cap can have more damaging effects on the overall economy since higher electricity prices feed through to further inflation. Although the ultimate performance of any scheme depends on the quality of information and the potential for welfare gains, the decision to implement should also consider the potential trade-offs among the goals of policymakers.

Despite the intuitive nature of these results, there are a few shortcomings. I assumed an environment of zero transmission and distribution losses, but losses can be substantial, especially in developing countries. Likewise, the static setting examined assumes that the firm's technology requirements are fixed and there is no dynamic interplay between the regulator and the firm. Nonetheless, one of the benefits of incentive regulation schemes is that over time regulators learn more about the firm's ability to reduce costs. It is also difficult to determine if these results can be generalised to unbundled markets especially where competition exists in wholesale and retail market segments. However, integration of these issues into future research would reveal more evidence about a particular scheme's desirability.

Table 4
Demand uncertainty and price cap regulation[a].

Variables	Optimal price cap	Price cap (known demand)
Residential tariff (%Δ)	−27.1126	−15.7037
Commercial tariff (%Δ)	36.8347	13.2751
Industrial tariff (%Δ)	12.2139	4.7144
Total output sold (%Δ)	6.9719	3.8426
ΔWelfare/customer (US$)	14.0206	17.7125

[a] Price cap (known demand) uses quantity weights from the previous period (2012) instead of the Ramsey quantity weights which are used for the optimal price cap. The change in each variable is the difference between values at the original prices and the new prices calculated for each scheme.

Acknowledgments

I wish to express my sincere gratitude to David Stern, Paul Burke, and anonymous referees for their useful and insightful comments. I would also like to thank the participants at the 2015 International Association of Energy Economists (IAAE) Conference in Turkey for their valuable feedback and comments.

Appendix A. Case studies of price and revenue cap schemes

In the following section, I provide three case study examples of other countries that have applied cap regulation to their electricity networks. I focus on issues related to privatization, structure of the industry, and the specific part of the industry to which incentive schemes are applied.

A.1. Trinidad and Tobago

The Trinidad and Tobago Electricity Commission (T&TEC) is the sole retailer of electricity in Trinidad and Tobago and has full responsibility for the design, construction, operation, and maintenance of the country's electrical transmission and distribution network, but the ownership structure differs in the sense that T&TEC is wholly owned by the government of Trinidad and Tobago (McGuire, 2007).

Even though Trinidad and Tobago's electricity sector was opened up to competition in 1993 to attract foreign investment, the network is still vertically integrated. Various legislations were amended which allowed T&TEC to form companies, hold shares, and operate its generation and transmission and distribution segments independently (Ministry of Energy and Energy Affairs, 2013). The state-owned T&TEC retains majority ownership in PowerGen – the largest generator, while Trinity Power and Trinidad Generation Unlimited (TGU) are privately owned. Together, all three IPPs have an installed capacity of approximately 2289 MW. Of this total, PowerGen produces 1344 MW and the rest is produced by Trinity Power and TGU.

The Regulated Industries Commission (RIC) was established in 2001 to supervise the operations of the two generators – Trinity Power and PowerGen; and T&TEC. Incentive regulation in Trinidad and Tobago is in the form of a revenue cap:

$$R_t = R_{t-1}[1 + (CGA \times CUST) + (RPI - X)] + Z \tag{A.1}$$

where R_{t-1} is the authorised revenue for time $t-1$, RPI is the annual change in prices, X is the reduction in prices imposed by the regulator, Z is a cost pass-through variable, $CUST$ is the annual change in the number of customers (or the annual change in output), and CGA is a customer growth factor which can be expressed in percentage terms. In Trinidad and Tobago, this fixed revenue cap regime took effect in June 2006 and covered a five-year regulatory period (Regulated Industries Commission, 2006).

A.2. United Kingdom

Prior to 2010, the United Kingdom pioneered the use of price cap regulation and applied it for over 20 years after wide-scale privatization and decoupling of state-owned network utilities in the late 1980s and early 1990s. In 1999, the Office of Gas and Electricity Markets (Ofgem) was established as the key oversight body for the industry after a merger between the Office of Energy Regulation (Offer) and the Office of Gas Regulation (Ofgas). The industry consists of over 436 generating facilities and over 70 electricity retailers with established competition in both segments (Mandel, 2014). Installed capacity was estimated at approximately 93,784 MW in 2012 (US Energy Information Administration, 2016). The transmission system operator – National Grid Company (NGC), and the distribution segment are regulated as natural monopolies and both are subject to price cap regulation under Ofgem oversight. The price cap sets the maximum base revenue the regulated businesses can earn for each year of the regulatory period. The price cap takes the form

$$p_t = p_{t-1}(1 + RPI - X) \tag{A.2}$$

where p_{t-1} is the price of electricity at the beginning of the price cap period, CPI is the annual rate of inflation and X is the offset to inflation (annual real price increase or decrease) resulting from productivity changes in the electricity industry. This '$RPI - X$' formula was applied to electric utilities in five-year regulatory periods in which Ofgem specified the maximum rates a utility could charge for its services. The UK currently uses the RIIO (Revenue = Incentives + Innovation + Outputs) model which is seen as an extension of price cap regulation.

A.3. Norway

Like the UK, competition in Norway's electricity sector has been encouraged through vertical separation. In 2012, installed capacity was approximately 32,283 MW with approximately 35% coming from hydro power (US Energy Information Administration, 2016). Statnett – Norway's transmission system operator, and its over 155 electricity distribution companies operate under a revenue cap introduced by the Norwegian Water Resources and Energy Directorate (NVE) in 1997 (Norwegian Water Resources and Energy Directorate, 2014). It sets an upper limit for revenues intended to cover the network's costs such as operation and maintenance of the grid, and earn a reasonable return on capital invested. The annual cap is based on 40% cost recovery and a 60% cost norm. A simplified version of the revenue cap formula is

$$R_t = 0.4C_{t-2} + 0.6C^*_{t-2} \tag{A.3}$$

where R_t is the revenue cap in year t and C_{t-2} is the two-year lag on the cost base for each network operator. C^*_{t-2} is the cost norm for each network company derived through benchmarking with local and regional utilities, and other international transmission operators in the case of Statnett. Statnett's cost norm is derived from the 2012 e3GRID study which analysed the cost efficiency of 22 transmission system operators in Europe.

References

Armstrong, M., Vickers, J., 2012. Consumer protection and contingent charges. J. Econ. Lit. 50 (2), 477–493.

Regulator, Australian Energy, 2013. AER Response to Productivity Commission Further Information Request. Australian Energy Regulator. Retrieved from URL https://www.aer.gov.au/system/files/AER%20response%20to%20Productivity%20Commission%20further%20information%20request%20-%2022%20February%2-02013.pdf.

Averch, H., Johnson, L.L., 1962. Behavior of the firm under regulatory constraint. Am. Econ. Rev. 52 (5), 1052–1069.

Bacon, R., Besant-Jones, J., 2001. Global electric power reform, privatization, and liberalization of the electric power industry in developing countries. Annu. Rev. Energy Environ. 26 (1), 331–359.

Banerjee, A., 2003. Does incentive regulation 'cause' degradation of retail telephone service quality? Inf. Econ. Policy 15 (2), 243–269.

Baumol, W.J., Bradford, D.F., 1970. Optimal departures from marginal cost pricing. Am. Econ. Rev. 60 (3), 265–283.

Brennan, T.J., 1989. Regulating by capping prices. J. Regul. Econ. 1 (2), 133–147.

Campbell, A., 2018. Price and income elasticities of electricity demand: evidence from Jamaica. Energy Econ. 69, 19–32.

Chen, Y., Hobbs, B.F., Ellis, J.H., Crowley, C., Joutz, F., 2015. Impacts of climate change on power sector NO_x emissions: a long-run analysis of the US mid-Atlantic region. Energy Policy 84, 11–21.

Comnes, G., Stoft, S., Greene, N., Hill, L., 1995. Performance-based Ratemaking for Electric Utilities: Review of Plans and Analysis of Economic and Resource Planning Issues. Vol. I. Oak Ridge National Laboratory, Oak Ridge, TN, and University of California, Berkeley.

Crew, M.A., Kleindorfer, P.R., 1996a. Incentive regulation in the United Kingdom and the United States: some lessons. J. Regul. Econ. 9 (3), 211–225.

Crew, M.A., Kleindorfer, P.R., 1996b. Price caps and revenue caps: incentives and disincentives for efficiency. In: Crew, M.A. (Ed.), Pricing and Regulatory Innovations Under Increasing Competition. Springer., pp. 39–52.

De Villemeur, E.B., Cremer, H., Roy, B., Toledano, J., 2003. Optimal pricing and price-cap regulation in the postal sector. J. Regul. Econ. 24 (1), 49–62.

Decker, C., 2009. Characteristics of alternative price control frameworks: an overview. Report for Ofgem, Retrieved from URL https://www.ofgem.gov.uk/ofgem-publications/52038/rpicharacteristics-alternative-price-control-frameworks270209.pdf.

Dutra, J., Menezes, F.M., Zheng, X., 2015. Price regulation and the incentives to pursue energy efficiency by minimizing network losses. Q. J. IAEE's Energy Econ. Educ. Found. 37 (4).

Hirst, E., Blank, E., Moskovitz, D., 1994. Alternative ways to decouple electric utility revenues from sales. Electr. J. 7 (6), 54–66.

Service, Jamaica Public, 2013a. JPS Annual Report 2013. Jamaica Public Service.Retrieved from URL http://www.myjpsco.com/wp-content/uploads/JPS-Annual-Report-2013.pdf.

Service, Jamaica Public, 2013b. Our History. Retrieved from URL http://www.myjpsco.com/about-us/our-history/.

Service, Jamaica Public, 2014. JPS Tariff Application: 2014–2019. Retrieved from URL http://www.our.org.jm/ourweb/sites/default/files/documents/sector_documents/jps_2014-2019_rate_review_application_742014-final.pdf.

Jamison, M., 2007. Regulation: price cap and revenue cap. Encycl. Energy Eng. Technol. 3, 1245–1251.

Jarvis, D.S., 2011. Infrastructure Regulation: What Works, Why and How Do We Know? Lessons From Asia and Beyond. World Scientific.

Joskow, P.L., 1997. Restructuring, competition and regulatory reform in the U.S. electricity sector. J. Econ. Perspect. 11 (3), 119–138. https://doi.org/10.2307/2138188.

Joskow, P.L., 2007. Regulation of natural monopoly. Handb. Law Econ. 2, 1227–1348.

Kopsakangas-Savolainen, M., 2004. The welfare effects of different pricing schemes for electricity distribution in Finland. Energy Policy 32 (12), 1429–1435.

Kopsakangas-Savolainen, M., Svento, R., 2010. Comparing welfare effects of different regulation schemes: an application to the electricity distribution industry. Energy Policy 38 (11), 7370–7377.

Kroeze, C., Vlasblom, J., Gupta, J., Boudri, C., Blok, K., 2004. The power sector in China and India: greenhouse gas emissions reduction potential and scenarios for 1990–2020. Energy Policy 32 (1), 55–76.

Kuosmanen, T., Saastamoinen, A., Sipiläinen, T., 2013. What is the best practice for benchmark regulation of electricity distribution? Comparison of DEA, SFA and StoNED methods. Energy Policy 61, 740–750.

Laffont, J.-J., Gremaq, I., Tirole, J., Geras, I., 1996. Creating competition through interconnection: theory and practice. J. Regul. Econ. 10 (3), 227–256.

Laffont, J.-J., Tirole, J., 1986. Using cost observation to regulate firms. J. Polit. Econ. 94 (3, Part 1), 614–641.

Laffont, J.-J., Tirole, J., 1993. A theory of incentives in procurement and regulation. MIT Press, Cambridge, MA.

Lantz, B., 2008. Hybrid revenue caps and incentive regulation. Energy Econ. 30 (3), 688–695.

Lyon, T.P., 1996. A model of sliding-scale regulation. J. Regul. Econ. 9 (3), 227–247.

Mandel, B., 2014. A Primer on Utility Regulation in the United Kingdom: Origins, Aims, and Mechanics of the RIIO Model. Frank J. Guarini Center on Environmental, Energy and Land Use Law.Retrieved from URL http://guarinicenter.org/wp-content/uploads/2015/01/RIIO-Issue-Brief.pdf.

McGuire, G., 2007. Competition in Energy Markets: Trinidad and Tobago Case Study. Retrieved from URL http://www.temp2.olade.org/documentos/T&TCase%20Study.pdf.

Ministry of Energy and Energy Affairs, 2013. Electric Power. Retrieved from URL http://www.energy.gov.tt/resources.php?mid=9.

Ministry of Energy and Mining, 2009. Jamaica's National Energy Policy: 2009–2030. Retrieved from URL http://mstem.gov.jm/sites/default/files/National%20Energy%20Policy.pdf.

Neu, W., 1993. Allocative inefficiency properties of price-cap regulation. J. Regul. Econ. 5 (2), 159–182.

Norwegian Water Resources and Energy Directorate, 2014. National Report. Retrieved from URL http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/NATIONAL_REPORTS/National_Reporting_2012/NR_En/C12_NR_Norway-EN.pdf.

Office of Utilities Regulation, 2004. Jamaica Public Service Company Limited Tariff Review for Period 2004–2009: Determination Notice. Retrieved from URL http://www.our.org.jm/ourweb/sectors/electricity/documents?type=72&page=1.

Parker, D., Kirkpatrick, C., 2005. Regulating prices and profits in utility industries in low-income economies: rate of return, price cap or sliding-scale regulation? Int. J. Public Sect. Manag. 18 (3), 241–255.

Potters, J., Rockenbach, B., Sadrieh, A., Van Damme, E., 2004. Collusion under yardstick competition: an experimental study. Int. J. Ind. Organ. 22 (7), 1017–1038.

Raineri, R., Giaconi, P., 2005. Price and access charge discrimination in electricity distribution: an application to the Chilean case. Energy Econ. 27 (5), 771–790.

Ramsey, F.P., 1927. A contribution to the theory of taxation. Econ. J. 37, 47–61.

Commission, Regulated Industries, 2006. Regulation of Electricity Transmission and Distribution June 01, 2006 to May 31, 2011: Final Determination (Rates and Miscellaneous Charges). Retrieved from URL http://www.ric.org.tt/home/ttec_rate_review/Regulation%20of%20Electricity%20Transmission%20and%20Distribution%20Final%20Determination.pdf.

Rogerson, W.P., 2003. Simple menus of contracts in cost-based procurement and regulation. Am. Econ. Rev. 93 (3), 919–926.

Sappington, D.E., 1994. Designing incentive regulation. Rev. Ind. Organ. 9 (3), 245–272.

Sappington, D.E., 2002. Price regulation and incentives. Handbook of Telecommunications, North-Holland, London.

Sappington, D.E., Sibley, D.S., 1992. Strategic nonlinear pricing under price-cap regulation. RAND J. Econ. 23 (1), 1–19.

Sappington, D.E., Weisman, D.L., 2010. Price cap regulation: what have we learned from 25 years of experience in the telecommunications industry? J. Regul. Econ. 38 (3), 227–257.

Shleifer, A., 1985. A theory of yardstick competition. RAND J. Econ. 16 (3), 319–327.

The European Bank for Reconstruction and Development Transition Indicators Methodology. Retrieved from URL https://www.ebrd.com/cs/Satellite?c=Content&cid=139523786624&d=Mobile&pagename=EBRD%2FContent%2FContentLayout.

Energy Information Administration, U.S., 2016. International Energy Statistics. Retrieved from URL http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=7.

Wirl, F., 1995. Impact of regulation on demand side conservation programs. J. Regul. Econ. 7 (1), 43–62.

Xie, B.-C., Shang, L.-F., Yang, S.-B., Yi, B.-W., 2014. Dynamic environmental efficiency evaluation of electric power industries: evidence from OECD (Organization for Economic Cooperation and Development) and BRIC (Brazil, Russia, India and China) countries. Energy 74 (1), 147–157.